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MAPPING AND SURVEYING PRACTICES ADAPTED TO USE IN LESS DEVELOPED AREAS

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Paper A.1. Mapping and Surveying Practices
Adapted to Use in Less Developed Areas

by

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INTRODUCTION

1. In the short space available it is of course impossible to give more than a general outline of this very large subject; but in this paper an attempt has been made both to describe, with examples, the kind of maps and surveys required for the development of countries outside Europe; and also to outline the processes involved. Where possible an indication has been given of whether in the author's opinion particular tasks are better done by Government or commercial organisations; and some of the common pitfalls are also indicated. Two fundamental points have been stressed throughout. The first is that a progressive approach should be adopted, with a gradual localisation of the surveys at increasingly larger scales as the site of the proposed development becomes more closely defined. The second is that all surveys should be based on a sound and permanently marked framework which will form part of the permanent survey structure of the country. A great deal of public money has been wasted in the past by initiating surveys (particularly of communications) with too narrow an approach; and also by economising on the framework which has then had to be done all over again a few years later.

REQUIREMENTS

2. The general requirements for maps and surveys in planning and carrying out development projects are now so clearly understood that we can proceed directly to consider them in detail without having to justify them. They can be divided into four categories:- (i) Regional mapping (ii) Engineering surveys for specific projects (iii) Cadastral Surveys (iv) Natural Resources Surveys. Sharp boundaries cannot be drawn between these categories since there is always some overlapping. For example by far the greater part of the mapping done by this Directorate is at 1/50,000 scale which is on the boundary between regional and project surveys. Although the areas selected are usually dictated by the requirements of particular projects, we always ensure that the maps are on

proper national sheet lines and are drawn on a reasonably consistent specification. More important, if there is time for us to put in a fresh control framework, we insist that this should be permanently marked and surveyed to the standards required for a national framework and for eventual breakdown to a closer network for large scale mapping. In this way, whether a specific project is carried out or not, the mapping done for it becomes a substantial and permanent contribution to the map of the country and to its survey structure.

3. Regional Mapping Before the war few countries outside Europe had any comprehensive map cover at scales larger than 1/250,000; but the extensive use of aerial survey has changed this. Large areas can now be covered rapidly at 1/100,000 or 1/50,000 scale expecially if contours are not demanded in the first instance. The initial efforts of this Directorate in the immediate post war years were therefore concentrated on covering as wide an area as possible with what were called 'preliminary plots'. The majority of these were single colour planimetric maps (i.e. without contours), perhaps also temporarily deficient in names and other local information, but otherwise usually accurate and suitable not only for immediate use, but also as a base for subsequent editions. By 1956 over 300,000 square miles had been mapped in this way in Africa alone, and these so-called "preliminary plots" served an extremely useful purpose in making possible the initial consideration of some of the larger projects and in narrowing down the areas where development was feasible, and where contours etc. would be required in subsequent editions. It is interesting to note that in the Sudan a similar approach was followed, whereas in countries (such as Iraq or Jordan) where regional mapping was done by blocks on contract the mapping was contoured from the start, but the control framework was generally of a lower standard.

4. Engineering Surveys In this section we may consider maps on scales from 1/50,000 to the largest scales at which maps are normally produced, i.e. about 1/500. Most maps of this kind are contoured, with intervals varying from 30 metres to one metre or even less. Examples are given below of various types of projects.

5. Hydro-electric Schemes The requirements are normally threefold:- small scale maps for the catchment; a medium scale for the reservoir; and large scale maps of the areas where actual earthwork and detailed design are required, i.e. the dam itself, main canal headworks, power stations, and the associated residential and office sites. Access roads and transmission lines require preliminary medium scale maps followed by strip mapping at large scales. In the catchment area the other data required are rainfall and run off and these are so uncertain and variable that existing regional maps on 1/100,000 or even smaller will therefore normally be adequate for any but very small schemes. The reservoir volume is required for estimating the amount of water held back by various heights of dam, and for this purpose a scale of 1/50,000 or 1/25,000 is usually adequate, with 5, 10 or 15 metre contours. There will be a requirement for a more accurate plan containing the limiting contour once this is known, with heights to within a metre or less. Evaporation, the effects of wind and pressure changes on the water surface, and the relatively unknown quantities of seepage and of silting will all affect the actual volume of water in the reservoir, and measured discharges into and out of it are also liable to errors of a few per cent. For selection of the dam site and the associated works the requirement is for maps on about 1/5,000 scale but for detailed design of the

chosen site, the computation of quantities of material to be removed, and of concrete or rock fill to be put in, scales of 1/1,000 or so with contour intervals of a metre or less are by no means uncommon.

6. Towns and Settlements The mapping requirement for towns or other forms of settlement depends principally on whether the area is open or already built over. For the former a contoured map on about 1/2,500 with one or two metre contours is usually adequate, but for the latter it may be necessary to go to 1/500 scale and show spot heights along the streets. In both cases reference marks for future use can only be put in initially along the perimeter and on any main streets unlikely to be changed.

7. Irrigation Schemes The principal requirement for an irrigation scheme is naturally extreme accuracy in heights; and since the land to be irrigated must be reasonably flat, the contour interval required is likely to be of the order of five metres or less in the very preliminary stages, and of a metre or less when it comes to planning the detailed lay out. With the very small slopes (perhaps as low as one in 10,000) found in areas suitable for irrigation, contours take on a different significance since their positions on the map may be subject to very considerable errors - a centimetre or so at map scale - and a more precise way of showing the relief is to use spot heights at regular intervals, with the contours drawn between them to indicate, rather than to specify accurately, the shape of the ground. This kind of close control is slow and expensive; and every effort should be made by preliminary topographical and soil surveys to eliminate areas which are too high or have too poor soil to be usable.

8. Routes For these a progressive approach is particularly desirable. There should be a preliminary reconnaissance 'map' (it may be simply a mosaic of air photographs) of a wide strip from which progressively narrower areas are then selected for more detailed study and mapping at increasingly large scales and with closer contouring. Unfortunately design contracts seem often to be arranged in such a way as to confine the survey work to the large scale strip map required for the final design and quantities, without requiring enough preliminary surveys at smaller scales to make sure that the route followed is the best one. The result of this short sighted policy may well be that the actual construction of the road, railway, or transmission line (and also its future maintenance) will cost the Government concerned a good deal more than it need; and the extra cost may well be several times the money saved on the original surveys.

9. Cadastral Surveys These are required to define clearly and accurately the individual properties into which the land is divided, so that each land owner may feel secure enough to spend money or effort in developing his property. With physical and visible boundaries as in Europe the cadastral map reflects clearly the visible division of the land; but elsewhere parcels of land have to be defined by a series of straight lines joining corner beacons. Where the cultivation and ownership patterns differ, the production of a cadastral map is not as easy as it seems. It is therefore extremely important in a relatively undeveloped country not to introduce land registration without a full realisation of what is required to make it work. Without it people will settle their problems satisfactorily at village or family level; especially of course when there is no great pressure on the land. But once the Government has embarked on the registration of land parcels, usually including a guarantee of title, it

must make sure that these can be properly identified and defined; and this can only be done by a cadastral survey of sufficient accuracy to meet the particular circumstances. This century can show far too many examples of a Government which has started a system based on sketch maps or even on no surveys at all; only to find itself after a few years quite unable to keep pace with or control the flood of worthless paper which has resulted; to keep track of changes of ownership, subdivision or amalgamation of parcels; or to settle the endless disputes over boundaries and ownership for whose settlement it has now become responsible.

10. The general purposes of cadastral surveys are therefore four:- (i) To define, locate, and index all parcels of land (ii) To restore at any time a disputed boundary (iii) To determine the areas of parcels for fiscal or economic purposes (iv) To keep a continuous and up to date record of the subdivision or amalgamation of the parcels as may be required on sale or inheritance or for such purposes as building development or consolidation for better farming methods. It is not possible here to expand on these individually, but three points may be noted:- First: uncertain boundaries, especially where pressure on the land is heavy, are a fruitful source of dispute; and proper survey records of the original boundary are indubitably the most satisfactory evidence for settling them when the survey is supported by permanent reference marks. Hedges, particularly in the tropics, may spread or grow in the wrong place or fail to grow at all; fences, walls, and corner beacons can be moved; but a boundary line or beacon whose original survey was connected to the properly marked control framework of the country can always be restored by reference to this, and any changes can be surveyed without any deterioration in accuracy. Secondly: the requirement for accurate areas means that the map must be properly surveyed and scaled; but areas should not be quoted too precisely or they may be found to conflict with the boundaries in defining the extent of each parcel. Finally, one must remember that a cadastral survey is a continuous process and that it must be kept up to date. The need for maintenance staff is the strongest argument for not having the whole initial survey done by an outside contract, since this does not leave behind staff who have taken part in the initial survey and have thereby received the training, interest, and pride in the structure which it will their duty thereafter to maintain.

12. <u>Natural Resources Surveys</u> Different climates have different potentialities and different soils have distinct management requirements. Over the centuries farmers learned to cope with these differences and characteristic systems of agriculture were developed in the various parts of the world. Now agricultural research, the production of artificial fertilizers, and mechanization have revolutionised agriculture in the temperate regions, and subsistence agriculture is giving way to cash cropping in the tropics. The cry of the less developed areas is for more food and increased production of export crops. How can this be achieved? The tropics are so different in their soils as well as their climates that farming techniques developed in the temperate regions cannot be introduced wholesale. Surveys and experimentation are needed to answer the following questions: How should a certain area be used? What crops should be produced? Could it be grazed, if so at what frequency and density? Does it contain exploitable timber? Is it being used to capacity already? In general, surveys are needed to provide geographical information on the natural resources and to supply the link between research worker and farmer. Outstanding results have been achieved on experimental farms in the tropics, but all too often these results have not led to increased yields over large areas owing to lack of survey

data. Experimental findings are only relevant to areas of similar soil and climate, and without maps and surveys it is impossible to know where those areas are or how extensive they are.

13. Surveys for agricultural and forestry development fall into three groups. First are surveys of directly exploitable resources: forest inventories including type mapping, location of economic species and calculation of volumes; pasture surveys comprising the mapping and analysis of the main communities, observation of seasonal changes and the assessment of livestock carrying capacity; and surveys of other economic species - e.g. the Shea Butternut Tree or gum-producing trees. The second group contains surveys of the agricultural environment: ecological and soil surveys to assess the suitability of land for different purposes and to provide a geographical framework for the findings of experimental stations. The third group comprises surveys of current land use: surveys of the mode and density of land use and the effect this use has on the land.

SURVEY AND MAPPING PROCESSES

14. Mapping can be broken down into the following six main steps: (i) The Basic Framework (ii) Aerial Photography (iii) The breakdown of the main framework into minor control (iv) Detail mapping (v) Ground Completion (vi) Fair drawing and printing. The compilation of special maps to show natural resources follows a different process and is described separately.

15. The Basic Framework, or Geodetic Survey The framework of any survey plays rather the same part in it as the steel framework of a modern building: it is essential for strength and for later repairs and modifications to the walls; but for most of the building's life it remains hidden and often forgotten. In mapping, an accurate framework is required to ensure a uniform scale and that there shall be no overlaps or gaps between the mapping of adjacent areas. The framework may be formed of points fixed in plan by astronomical observations, radar distances, triangulation, or traverse, or by a combination of these; and heights may be obtained by spirit levelling or by vertical angles between the triangulation or traverse points, but the first two methods by themselves are only of value in the very preliminary stages of mapping a country, although they are of great use in combination with the other methods.

16. Until a few years ago triangulation was used for all major frameworks, except occasionally in countries such as Nigeria and Ghana where low relief and thick forest made it necessary to rely on precise taped traverses along the roads and railways. Now that distances up to 40 miles or more can be measured electronically with great accuracy and speed, most frameworks are being built up by a combination of distance and angle measurement that falls somewhere between triangulation and traverse. The speed of working is now very great; for example this Directorate ran a precise Tellurometer traverse of 600 kilometres in Kenya in 1957 in one month; a task which by other means would have taken at least two seasons; and in Sarawak recently one of our surveyors established 53 points covering a distance of nearly 500 kilometres in five and a half months through thickly forested country.

There is a temptation in the rush for development to be content with a basic framework of a standard adequate only for the immediate purpose; but it must be

realised that a sound geodetic framework, accurately surveyed and permanently marked (preferably by concrete pillars) is the best survey asset any country can have; and it has been the policy of this Directorate to concentrate its field staff on doing this, and to provide temporary and less accurate work only when there is no time to do otherwise. This work does not lend itself readily to being done by contract because its very nature demands a permanent staff of highly qualified surveyors working to close specifications, without being pressed to cut corners or meet contract dates.

17. The provision of a basic framework of accurate heights is generally an easier proposition than the planimetric control since even the most precise levelling is a relatively straight-forward process which can be carried out by less highly trained surveyors under supervision, especially since the level lines can follow established lines of communication. Heights can be carried along the plan framework by observing vertical angles; but this is a good deal less accurate. Here again permanent marking of the level bench-marks is essential and as many as possible should be sunk in rock. Barometric heighting is not accurate enough for the basic framework.

18. Aerial Photography The greater part of topographical mapping is now done from aerial photographs, most of them taken with the camera axis vertical. The exposure interval is adjusted so that along each strip there is a forward overlap of about 60%, and adjacent strips overlap laterally by about 25%. Thus every part of the ground is covered by at least two photographs and can be viewed stereoscopically. This makes possible the appreciation of relief and thus the drawing of contours; and it also greatly increases the possibility of interpreting the photographs correctly, since the actual shapes and heights of objects can be appreciated and detached from their shadows. Photographs can now be taken at very small scales from great heights, but this limits their usefulness for interpretation and even for topographical mapping since small villages, tracks, and even minor railways cannot be seen. Oblique photographs are now scarcely used. The taking of vertical photographs is a highly skilled process, especially in areas where the maps are inaccurate. Navigation can be either radar controlled, as in the early days of British Royal Air Force photography overseas, or visual using various techniques. It is essential in any extensive photographic task to set up a processing laboratory within reach of the aerodrome from which the aircraft is operating, in order to provide rough prints which are used in the air for navigation, to keep a daily check on the cover completed, and to ensure that correct exposures are used.

19. Several newly independent countries have set up their own organisations for aerial photography, usually in conjunction with their local air line or air force. While this may be effective and economical for either very small areas such as individual towns, or for very extensive preliminary coverage at small scales, it seldom results in a standard of either navigation or photography which can compare with results obtained by the specialist commercial air survey companies. The result is that the best and most economical use cannot be made of the photography and it often has to be repeated when accurate mapping is required.

20. Minor Control Until the last few years the basic framework of points already described, which are as a rule twenty or more kilometres apart, had to be broken down by similar methods of ground triangulation or traverse into a close network of minor control points within which the detail survey could be carried

out by relatively simple methods, either on the ground or from air photographs. But the use of more stable film, more refined stereoscopic measuring and plotting machines, and modern computers have made it possible to achieve astonishing accuracies by aero-triangulation using the geometrical properties of the air photographs. In some cases these accuracies exceed one part in twenty thousand in plan and are therefore as good as second order frameworks surveyed on the ground. The stage has now been reached that for many mapping tasks, particularly at medium scales, the survey plan control put on the ground can be relatively widely spaced at intervals covering several photographs, with the network of minor control between provided entirely by the photography. This is less true of heights; and where close contouring is required, as at larger scales than 1/50,000 or for irrigation schemes, then the basic framework of precise levelling has to be broken down by a network of minor level lines. For more rugged country heights may be measured by barometer. As far as possible a proportion at least of these minor control points should be marked on the ground, since they will then form an invaluable local datum on which larger scale surveys for specific projects, or for setting out of actual construction works, can be based.

21. Detail Mapping It is in detail mapping that air photographs have really taken over; detailed surveys on the ground are now usually restricted to regions where weather or forest cover prevent air photography and to small areas for which photography would be uneconomical. Even cadastral surveys, particularly where the boundaries are visible from the air, can now often be done from air photographs. Once we have obtained, either by ground survey or by aerotriangulation, the positions and heights of at least three points on every overlapping pair of photographs, each pair can then be put in a stereoscopic plotting machine and the resulting three-dimensional model can be correctly scaled and levelled. All topographical features in this model can be plotted as detail or contours, and so piece by piece the map as a whole is built up, the basic and minor control frameworks ensuring that each piece will fit exactly into its proper place, regardless of the order in which it is put together or of how many different machines and operators are used.

22. In the plotting machines the two photographs are either projected down in complementary colours onto a table and viewed by the operator with coloured spectacles; or the three-dimensional problem is solved mechanically, the operator viewing the image through binoculars and moving a small dot in the field of view over the surface of the model to trace out features and contours. With the most refined and expensive instruments the plotting scale can be up to eight times that of the photographs; and with good photography and frequent height control contours can be plotted with an interval as small as 0.05% of the height above ground from which the photographs were taken. It is using a smaller scale of photography and consequently fewer photographs and less ground control which pays for the more expensive instruments; but these require a higher degree of sophistication and experience in their operation. An aerial survey unit in a less developed country should therefore rely initially on simpler methods and equipment until the required degree of experience is reached for the more advanced instruments. Too many of these are not being used because of the lack of trained operators; while under more realistic arrangements elsewhere very effective maps are being turned out at less cost by less sophisticated methods.

23. Ground Completion With the virtual replacement of ground survey of detail by air survey, the collection of local information such as the classification of

roads and the collection of names has become a separate process; and this is normally carried out on photographic copies of the photogrammetric plot before the latter is fair drawn. The best agency for ground completion is the local survey department; but a proper specification has to be drawn up for the various classes into which roads and similar details may fall, with definitions in sufficient detail to ensure that the field classifiers do their work uniformly.

25. Fair Drawing and Printing The accurate document produced by the photogrammetrist or field surveyor then has to be fair drawn and separated into as many colours as are required on the final map. This is nowadays done on special plastic sheets with names printed separately and added to them; and the lithographic printing plates are made from these. The smaller Survey departments tend either to have their printing done elsewhere or to undertake other government printing as well to keep their machines fully occupied.

26. Compilation of Special Maps to show Natural Resources The methods used to compile natural resources maps are as various as the different kinds of survey. There are few surveys however, in which aerial photographs are not of the greatest value, and they are particularly valuable in natural resources surveys since they present a detailed picture in which the interrelated patterns of soils and vegetation, rock types, landscapes and drainage, land use and settlement can be observed separately or in combination. The print laydown (uncontrolled mosaic) is another important tool which is particularly useful for breaking down large tracts into manageable units by establishing the main distributions of the landscape and vegetation types, and as a base for recording the findings of special surveys in areas that lack adequate topographic maps. A stylised programme for land use development surveys would include the following stages: (i) Compilation and correlation of the existing data. (ii) Aerial photograph interpretation to produce a type map. (iii) Studies on the ground to check the aerial photograph interpretation and to analyse the different units. (iv) Production of report and field-revised maps.

27. The programme could often be improved by two additional stages between (i) and (ii), viz, a preliminary examination of the aerial photographs, and a short period of field work to establish standards for the full aerial photograph interpretation. Time and cost generally preclude these additional stages. Occasionally a special programme of field work is not essential, e.g. when an area is well documented or when only a simple break-down of types is required. Other surveys - notably pasture surveys - rely more on field work than aerial photograph interpretation, but may use a print laydown to record their results. Where adequate topographic maps on regular sheet lines are available, or can readily be made from the air photographs, they would normally be used as a base on which to overprint the special information relating to natural resources, perhaps after the deletion of some topographic information or the special printing of topographic information in a neutral colour such as grey.

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